# Solar potential on Auckland rooftops based on LiDAR data ☆

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**Abstract**

The energy system transition brought on by accessible solar power systems and home storage technologies will have implications beyond the technical solutions. In New Zealand solar power has been rapidly growing with the total installed capacity increasing from just 5 MW in August 2013 to more than 35 MW in March 2016. Most of the growth has taken place in the residential sector. Auckland Council has a goal of powering the equivalent of 176 565 homes by solar photovoltaics by 2040. To assess what this might translate to in terms of the number and size of solar installations we first need to assess the solar energy potential on Auckland rooftops. In this study we have used LiDAR data to develop a digital surface model of the city, including topography, buildings and trees. With this model a solar radiation tool has been used to calculate the annual solar radiation on each square meter of roof area, taking into account latitude, time of year, time of day, average climatic conditions, surface orientation and slope, and shading from nearby buildings and trees. This document gives some background to the use of LiDAR data used for solar potential assessment and the details of the methodology used to treat the data and provide the resulting raster files.

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**Contents**



## 1. Introduction

Renewable energy and energy storage are two of twelve potentially economically disruptive technologies, with potential to disrupt the status quo, alter the way people live and work, and ultimately lead to entirely new products and services, as reported by the McKinsey Global Institute [1]. According to the report lithium-ion battery packs used in electric vehicles have seen a price decline of 40 percent since 2009, and the price of a solar photovoltaic (PV) cell per watt has declined by 85 percent since 2000. It is indeed the combination of a innovative technology with economic availability that allows a technology to become potentially disruptive.

Solar power has been rapidly growing in New Zealand with total installed capacity increasing from just 5 MW in August 2013 to more than 40 MW in August 2016. Most of the growth has taken place in the residential sector. Auckland Council has a goal of generating the power equivalent of 176 565 homes by solar PV by 2040, yet in August 2016 the installed solar PV capacity was just 2700 installations (or 10 MW).

If the current growth trend continues, the electricity retail sector is likely to experience significant changes in its operation and pricing mechanisms. New Zealand retailars have already shifted away from paying their customers for solar power fed into the grid, while some lines companies have introduced a higher fixed charge to customers with solar power. While this might discourage uptake, the decrease in price of both solar cells and batteries is likely to incentivise consumers to invest in solar installations, and possibly, with the current signals from the market, to take a step further and invest in storage and a back-up system, such as a small-scale diesel generator, enabling them to go off-grid althogether.

Not only would this have a potentially negative impact on the carbon emissions of New Zealand's electricity generation, it would also leave a lower number of people paying for the costs of maintaining the grid, those generally being the customers who can't afford to invest in solar, battery and back-up technologies. To assess the potential magnitude of such a shift and initiate any discussion on its policy implications, it is necessary to accurately assess the solar radiation in the residential sector of the region, with a spatial resolution that is relevant for assessing solar potential in relation to demographics such as household income in different suburbs.

Section 2 provides the background and motivation for the research, section 3 goes through the various steps in our methodology, section 4 presents the data we have used, section 5 provides some examples from results.

## 2. Background

Mapping solar radiation in urban areas has become popular in many cities, including Boston [2] (USA), Wellington (New Zealand) [3] and Southampton (UK) [4], giving valuable information to urban planners and residents.

Several studies have used aerial imagery to estimate rooftop areas for solar potential calculation. Wiginton et al. (2010) [5] calculated solar energy potential for an entire region by applying feature recognition algorithms on high-resolution digital orthophotos. With this they could extract the rooftops and extrapolate their results for each geographical sub-division separately.

Ghosh and Vale (2006) [6] calculated the solar potential for a residential neighbourhood in New Zealand. They used aerial photographs to evaluate the shape and orientation of roofs and calculate daily solar radiation on roof surfaces facing +/-45 degrees north. Thier approach did not include the slope of roof surfaces or shading by trees and other objects in their calculation.

They conclude that significant contributions to $CO_2$ reductions can be achieved by orienting the roofs appropriately for maximising solar potential. They also note that many buildings with an area smaller than 20 $m^2$ are generally garages and garden sheds, but could potentially be well suited for a 4 square meter solar water heater, and thus should not be automatically excluded from solar potential studies.

Ortho-image analysis was also used by Bergamasco and Asinari [7] for solar energy potential assessment.They conclude that the computation of shadowing and roof brightness still remains an open issue, requiring indeed a complete 3D city model.

As a response, elevation data using LiDAR techniques have more recently been used to include the three dimensional aspects of rooftops and surrounding terrain.

### *2.1. LiDAR data for solar potential assessment*

LiDAR (Light Detection and Ranging) is a spatial data collection technology that uses light waves (specifically, the laser light) to sample the surface of the earth. It is a powerful earth observation tool that provides highly accurate 3D information of target areas. By recording reflected pulses of laser light from ground objects along with the signal return time, LiDAR systems directly measure the height of ground objects and store it in high-dense points that also contain other attributes such as classification, planar coordinates, GPS time, scan angle, etc.

From the aggregation of these points, also know as point cloud, high-resolution spatial information in both planar and vertical dimensions can be derived. This high-resolution spatial information can be used to delineate building footprints and structures with high accuracy [8]. Ultimately, based on the high-dense point cloud, a high resolution digital elevation model (DEM) can be generated to enhance the delineation of terrain features [8]. Therefore, LiDAR data has been successively used for building footprints and height extraction in a variety of urban areas [9, 10]. LiDAR technology is also cost-effective. It can be up to 70% cheaper than traditional photogrammetric methods in terms of generating DEM products [11]. It is also less time-consuming and has a higher degree of automation in data collection, processing and information extraction [12].

Solar radiation tools have previously been combined with digital terrain models to assess the influx of solar radiation on a surface over a day and over seasons. Nguyeg and Pearce (2010) [13] used *r.sun* software package and Geographical Resources Analysis Support System to calculate the solar potential for large scale solar power projects in fourteen counties in South-eastern Ontario, Canada at a spatial resolution on 1 square km.

To calculate solar potential on rooftops a trade off between total area size and building details is common. Izquierdo et al. (2008) estimated the photovoltaic potential in all regions of Spain based on a finite set of average building types [14].

Several other studies use a small area such as a block of houses or a neighbourhood, to calculate solar energy potential on rooftops, taking in to account the shapes and orientations of every rooftop individually [6, 15, 16, 17]. Redweik et al. (2013) [18] used LiDAR data to assess solar potential of both rooftops and building facades for university campus area, with a spatial resolution of 1 square meter. Brito et al. (2012) [19] used LiDAR data for a neighbourhood of 538 buildings to estimate the solar PV potential of the rooftops.

Thus, LiDAR data has been been increasingly used in solar energy system assessment and design [15, 20, 21], and given the above-mentioned advantages of the LiDAR technology, coupled with the availability of LiDAR data in our study area, it is quite cost-effective and feasible to conduct building roof extraction based on LiDAR data.

Where we have taken this methodology a step further is in covering an area of 2250 square kilometers, assessing the solar potential on each rooftop with a spatial resolution of 1 square meter. To demonstrate the value of this approach to policy making, we have aggregated solar radiation data per rooftop to a suburb level, which is relevant when comparing to demographic data such as household income.

### *2.2. Solar potential assessment in urban areas*

Various approaches have been applied to estimate the solar energy potential in urban areas for policy insights. Hofierka and Kaňuk [22] used a combination of topographic maps, orthophotomaps and building footprints to assess the photovoltaic potential on various urban zones characterised by morphology and functionality. With a spatial resolution of 1 square meter they covered a total of 1444 buildings. Their 3-D city model comprises of topographic information, not including the shading from trees and other nearby objects, and they conclude that a more complete 3-D model together with for example socio-demographic statistics could better reflect properties of various intra-urban structures.

Ordóñez et al. [23] analised the photovoltaic solar energy capacity of residential rooftops in Andalusia, Spain, by categorising the building sector on building characteristics and calculating the useful roof surface area for photovoltaic system installations. They analised a total of 18,520 buildings and show the importance of the design of roof-mounted elements when it comes to optimising energy production.

Hachem et al. [24] investigate the influence of geometric shapes of housing units, the density of units and different neighbourhood layouts on solar energy potential. The results indicate that total electricity generation is affected by both shape and orientation. Based on differences in roof shapes and neighbourhood layouts, we expect our results to differentiate between neighbourhoods in this manner as well.

Wiginton et al. (2010) [5] also assessed the solar energy rooftop potential in their region of study in relation to population density, finding a near linear relationship between roof area and population, although roof area per capita shows an increase in the less densely populated regions. They indicate that the more rural regions offer a particularly large opportunity for rooftop PV deployment, especially given the higher electricity transmission costs in rural regions. This also reflects the necessity for lines companies to weigh costs of solar PV and storage systems against the costs of maintenance and upgrades of existing lines or the installment of new lines for potentially fewer customers.

More recently, neighbourhood-scale has become a commonly used approach for studies concerning urban planning and design in growing cities. The potential to generate renewable energy within city boundaries is a topic of wide interest both in research and municipal planning. Sarralde et al. [25] studied the relationship between aggregated urban form descriptors and the potential to harvest solar energy within Greater London. To model urban morphology they used so called Lower Layer Super Output Areas (LSOA), which are assumed to represent typical neighbourhoods of Greater London.

Berg [26] describes seven dynamic aspects of sustainability, including physical resources, economic resources, social and organisational resources, that were used to model a community and study how the management of these aspects can be used to optimise the sustainability conditions of unique local communities of the city. They conclude that the dynamic model allowed them to compare different parts of the city with different site and situation-specific properties. Therefore the neighbourhood unit was a useful base, being small enough to be studied thoroughly and large enough to represent the different townscape types of the city.

This indicates the potential of our results, which are aggregated to the neighbourhood level, to be relevant for future research, beyond the study of solar potential to a broader assessment of local opportunities. In fact, as LiDAR data is becoming commonly available in most metropolitan areas, our research presents a reliable bottom-up tool for detailed analysis of the solar energy potential of the existing individual rooftops for a region or municipality, which can be readily aggregated to the relevant area unit, commonly the neighbourhood level. As we present in this paper, such results can be combined with socio-economic data, such as household income, to assess potential opportunities, challenges and policy needs to assure an equitable transition to distributed generation that optimises the use of local resources, in this case solar energy.

## 3. Methodology

### *3.1. LiDAR data processing*

Given the large amount of data points in the LiDAR point cloud dataset, a LiDAR dataset is typically separated into tiles for further data handling. However, processing the data points at the tile edges can be problematic as many of the algorithms, such as distinguishing between ground and above-ground points, need to consider the 3-D spatial relationship of the current point and surrounding ones. To avoid this edge effect, the whole dataset was redivided into tiles of 1000 m by 1000 m with a 50 m buffer zone among adjacent tiles. In each tile, the data points were classified into two categories: ground and above-ground points. The height of above-ground points is given as the absolute elevation above the ground, which was defined by the ground points. The height of the ground points is given as the elevation above mean sea level, and, in our case, the datum is defined as the New Zealand Traverse Mercator. The ground and above-ground points were then used to generate a digital terrain model (DTM) and a digital surface model (DSM), respectively.

The resulting raster files, one per neighbourhood, contain four bands which correspond to:

1. Annual solar radiation, $kWh/m^2$,
2. Slope of the rooftop area, in degrees (Note that some values may reflect vertical surfaces, or trees overlaying roof areas.),
3. Aspect of the rooftop, orientation clockwise from north, in degrees,
4. Elevation from sea level, $m$.

*3.2. Solar radiation modelling*

To calculate the solar radiation on each square meter of roof area, we use the solar radiation toolkit in ArcGIS software. This model takes in to account climatic features such as atmospheric transmissivity and the proportion of diffuse radiation. The details of the solar radiation modelling can be found at [27].

The amount of solar radiation received by the surface is only a portion of what would be received outside the atmosphere. Transmittivity of the atmosphere is expressed as the ratio of the energy reaching the earth's surface to that which is received at the upper limit of the atmosphere. Values range from 0 (no transmission) to 1 (complete transmission). Typically observed values are 0.6 or 0.7 for very clear sky conditions and 0.5 for a generally clear sky. To estimate the atmospheric conditions of Auckland, we apply an atmospheric transmissivity factor of 0.5. Similarly, the factor for the proportion of global normal radiation flux that is diffuse can take values from 0 to 1. We have applied the default value of 0.3, which corresponds to "generally clear sky conditions".

*3.3. Aggregating by house and suburb*

To estimate the solar radiation potential for an individual house, we consider current residential scale solar power technologies, and the areas that different size systems would occupy on the rooftop. Currently the average size of solar PV installation in New Zealand in roughly two to three kilo-Watts (kW). We estimate a 2 kW system to require a roof top area of roughly 14 $m^2$ and a 3 kW system to require 20 $m^2$ of roof area and calculate the total annual solar radiatiom on the 14 and 20 $m^2$ of roof area with the highest annual solar radiation.

To reflect future systems with batteries, we also calculate results for the 28 and 36 $m^2$ roof areas with highest solar radiation, roughly corresponding to 5 kW and 7 kW sized PV systems.

Thus, for each roof top we calculate the annual radiation of the 14, 20, 28 and 36 $m^2$ that receive the highest annual solar radiation. These calculations reflect the assumption that eventual solar panels are placed on the area of roof that receives most solar radiation over the year. We do not account for a case where the $m^2$ that receive the highest total annual radiation may be located on different segments of the roof, but could be on several different segments of the roof, meaning that optimising the solar installation to maximise total annual solar radiation, may require installing the panels in several smaller arrays.

To compare aggregate the solar energy potential of individual houses per suburb, we calculate the average annual solar radiation for the 14, 20, 28 and 36 $m^2$ of roof area with the highest annual solar radiation of all the buildings in each suburb. Since our study focuses on residential areas, we have excluded suburbs with mainly industrial buildings, but we have not distiguished between different building types in the suburbs that we have included in this study.

## 4. Data

### *4.1. LiDAR data*

The LiDAR data used in this study were provided by Auckland Council, delivered by NZ Aerial Mapping and Aerial Surveys Ltd. This dataset was collected during July to November, 2013, using Optech LiDAR sensors (models ALTM3100, Orion M200 and Orion H300). The final LiDAR point cloud product was featured by minimum 1.5 points per square meter (in open areas) and +/- 0.1 m vertical accuracy. This point cloud product that consists of 6511 tiles of 480 m by 720 m was stored in .las format files.

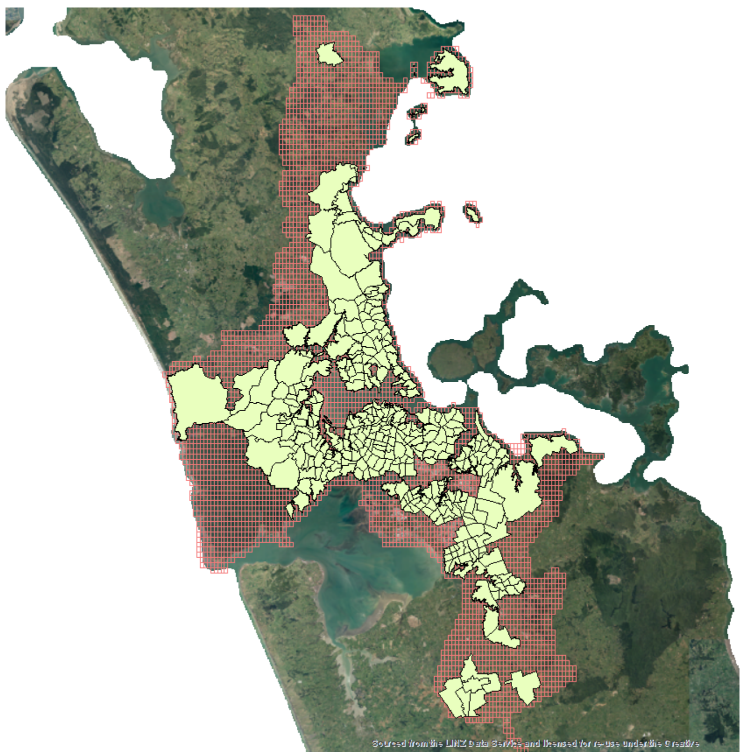

Figure 1: Extent of LiDAR data collection (rectangles) in the Auckland region and the selected residential suburbs.

### *4.2. Building and suburb outlines*

To define which points are from rooftops we used shapefiles for building footprints, provided by Auckland Council. To define suburbs, we use 2013 census geographical boundaries of so called *area units* [29]. Area units within urban areas normally contain a population of 3,000-5,000 people, and are generally recognised by name by residents. We select the suburbs with mainly residential buildings, resulting in 334 area units, holding a total of 649,141 building rooftops. Due to the possibility of using roof areas as small as four square meters for solar hot water or small solar power installations, we have not set a minimum roof area when calculating solar radiation per square meter of rooftop. Thus our building set includes separate garages and garden sheds, as long as they are included in the council's building footprints database. However, smaller than 20 $m^2$ buildings are excluded from the results for solar PV potential, due to the size of typical residential PV installations.

Figure 6 shows the extent of the original LiDAR data and the regional area units included in our study. Excluded areas are either sparesly populated, industrial, or have only partial LiDAR data coverage.

## 5. Results

### *5.1. Solar radiation per house and neighbourhood*

Figure 2 shows the distribution of total annual solar radiation on the top 14, 20, 28 and 36 $m^2$ of roof area. As can be expected, the distribution spreads out towards the left as larger rooftop areas are covered. Figure 3 shows the annual radiation results for a subset of rooftops from one suburb and how those rooftops can be rated by annual solar radiation based on the area with the highest results. The figure also confirms that most often the square meters with the highest solar radiation results are adjacent to each other, indicating it is a reasonable statistical metric for the radiation that a solar PV installation would receive if placed on that location on the rooftop. However, if looking at an individual rooftop with the intention of installing a solar PV system of

Table 1: Rating scheme for rooftops based on annual solar radiation, which can be applied to the average solar radiation on a given area of highest solar radiation.

| Rating | Annual radiation $kWh/m^2$ | Share of rooftops |
|---|---|---|
| 1 | <1100 | 3.7% |
| 2 | 1100–1200 | 4.6% |
| 3 | 1200–1300 | 18.0% |
| 4 | 1300–1400 | 71.8% |
| 5 | 1400–1500 | 1.9% |

a certain size, it is important to assess the results in relation to the actual roof configuration and see whether the results are indeed from one or several segments of that roof.

Figure 4 shows the results of a simple rating scheme used to visually compare suburbs. The ratings are given in table 5.1. The figure shows how the buildings constructed more systematically with a north-south orientation (figure 4 right) in a newer suburb have a higher rating than the rooftops in the older suburb with more variety in building orientation and larger, more mature trees.

Figure 5 gives the annual solar radiation on the selected roof areas ordered from highest to lowest, with the plot cropped at 1000 $kWh/m^2$. While few houses have a solar potential of over 1400 $kWh/m^2$, this graph provides an estimate of buildings feasible for PV installations given a certain minimum annual radiation level.

The average annual solar radiation of the buildings' top 14, 20, 28 and 36 $m^2$ gives an indicative rating of the rooftops in a suburb, by potential PV system size. Figure 6 these results for small PV systems i.e. the top 14 $m^2$ of rooftops. The results range from 1121 $kWh/m^2/yr$ to 1372 $kWh/m^2/yr$. However, the resulting number is unimportant to individual houses, and this figure should rather be used as a starting point to understand the differences in building types, topography and vegetation between different suburbs.

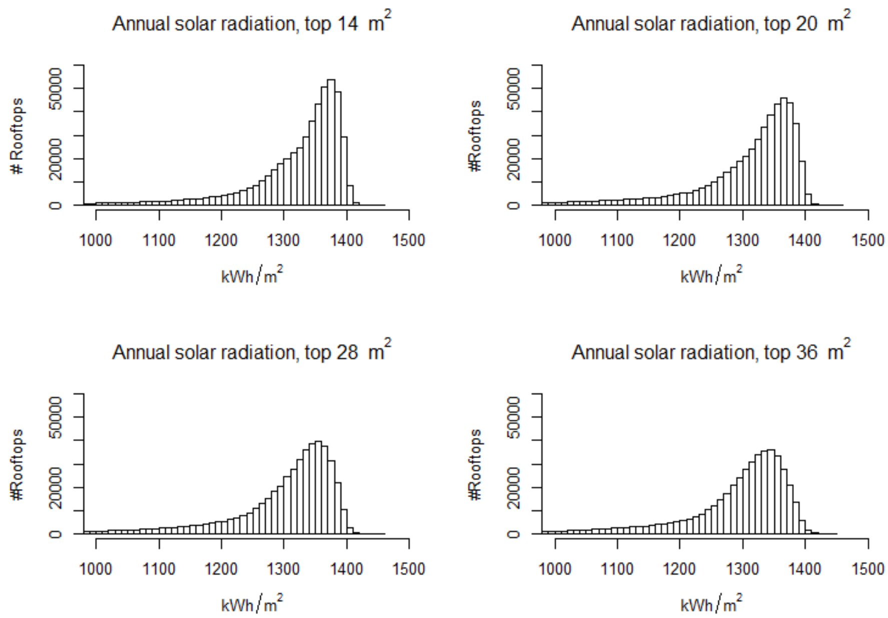


Figure 2: Annual solar radiation on the top 14, 20, 28 and 36 $m^2$ of all rooftops.

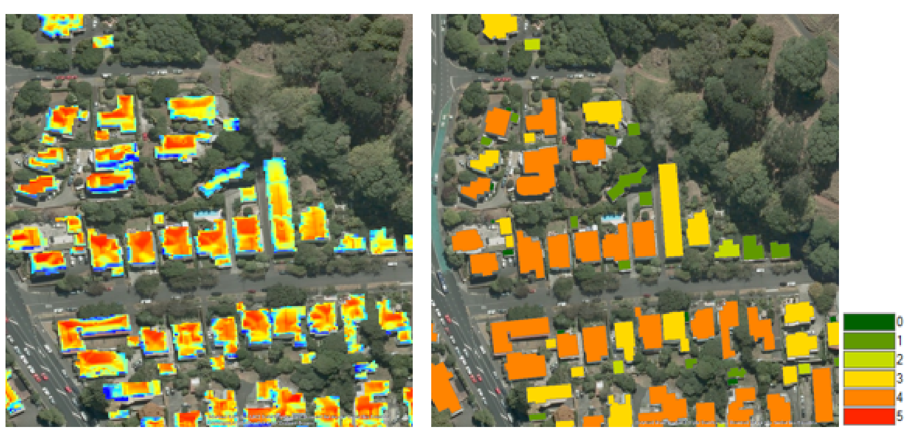


Figure 3: Results for annual solar radiation on a set of rooftops (left) and a simple rating scheme based on the 14 $m^2$ with the highest results (right), with 5 (red) for the highest and 0 (dark green) for lowest rating.


Figure 4: Results from rating rooftops based on the annual solar radiation on the 14 $m^2$ with the highest results in an older suburb (left) and a more recently built suburb (right).

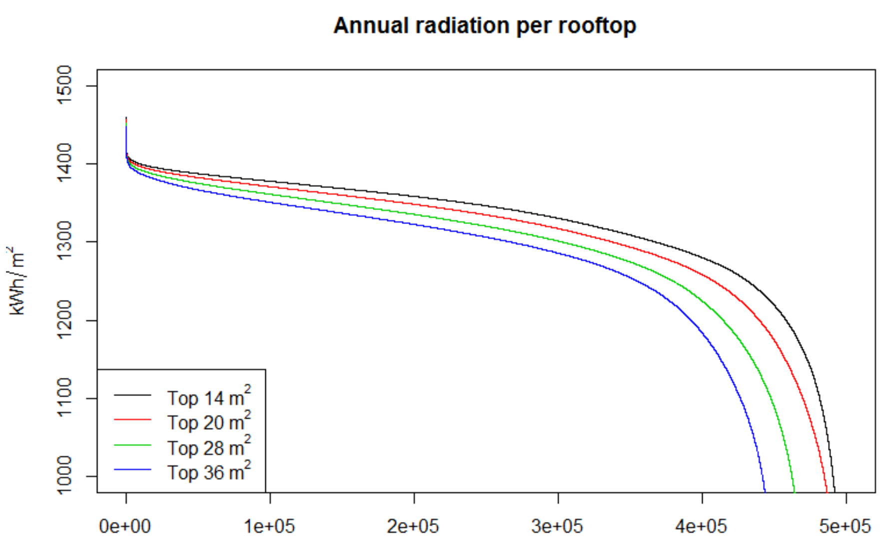


Figure 5: All rooftops sorted by annual solar radiation on for the four selected areas.

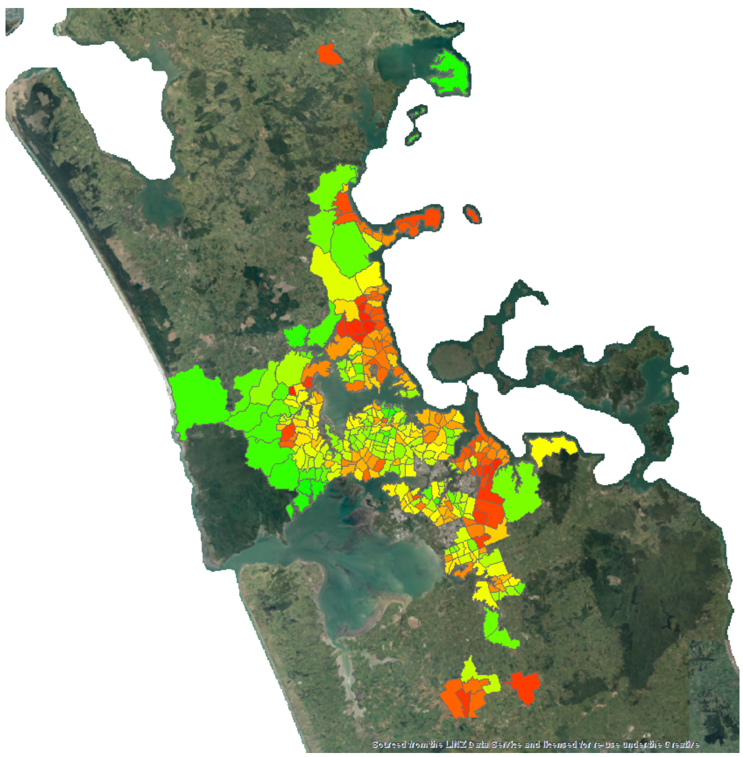


Figure 6: Rating of suburbs by average annual solar radiation on the top 14 $m^2$ of rooftops.

## 6. Discussion

This paper demonstrated the use of LiDAR data for bottom-up assessment of rooftop solar potential for a larger area than is typically found in literature. We have aggregated results to a suburb level to provide information for policy and municipal planning purposes. Although visualisation of results at house level gives direct information to residents about the level of annual solar radiation and the sunniest location on their rooftop, these results should not be used for investment decisions. The approach we have used is statistical and assumes certain parameters for transmissivity that may need correction. Also, local climatic effect such as typical cloudiness during a certain time of day, or local seasonal effects, are not accounted for. Thus, rather than being highly accurate on local weather, our model is highly accurate on rooftop shapes and the shapes and heights of, and hence shading by, nearby objects. We expect the results to accurately reflect the relative annual solar energy potential of rooftops. However, a detailed assessment of any individual site should be carried out for actual decision making purposes.

A comparison with a solar radiation tool based on measured solar radiation data has showed that our results underestimate the annual solar radiation by 3-5% on the sunniest spots on the roof. Also, our model assumes trees to be opaque, which is not entirely true in general, especially in winter for deciduous trees. As a next step to improve the model, we suggest linking the LiDAR based digital elevation model with a solar radiation calculator using measured solar radiation data.

Using NIWA's SolarView data with the digital elevation model we have developed would be a reasonable next step in developing the approach for solar potential assessment of individual houses. This would provide a tool with high spatial resolution coupled with locally measured solar radiation data, which would better account for local effects of nearby buildings, trees and variable cloudiness across days and seasons.

## 7. Conclusions

LiDAR data has become increasingly available and is commonly used solar radiation assessment. It provides a cost-effective technique to generate a detailed digital elevation model of a roof and its surroundings, whoch often used digital terrain models do not provide.

Based on our aggregated results we conclude that there are large differences of solar energy potential between individual houses and even at the suburb level. Some neighbourhoods are more systematically built with north-south oriented roofs, which is generally best suited for solar energy applications. Also, older, historical neighbourhoods tend to have more fully grown trees that cause more shading than more recently developed residential areas, which can also have some impact on results.

Future research could include developing a model for individual rooftops and/or investigation of market models for low-income customers to participate in solar energy generation.


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